# AN ANALYSIS OF THE CYCLE OF SMALL COMPRESSION IGNITION ENGINES

BY

CHENG SHIH

B.S., Peiyang University, 1939
M.S., University of Illinois, 1948

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN MECHANICAL ENGINEERING
IN THE GRADUATE COLLEGE OF THE
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# AN ANALYSIS OF THE CYCLE OF SMALL COMPRESSION IGNITION ENGINES

An analysis of all the processes making up the working cycle of a small compression-ignition engine by means of indicator diagrams, taking into consideration the heat exchange between the working medium and the cylinder walls, is presented. The engine used was a small twin-cylinder four-stroke cycle solid injection marine engine of 15 BHP at 800 RPM, and at four different loads from one quarter to full load for each speed.

Assuming that all processes are reversible, the work done on the medium or by the medium between any two states *1* and *2* is given by $\int_{v_1}^{v_2} p \, dv$ and may be expressed as $1/n - 1 \; (p_1v_1 - p_2v_2)$ provided that the process is polytropic, $n$ being the exponent of the polytropic curve, and $p$ and $v$ the pressures and volumes respectively, of the medium at the designated states, all of which can be determined from the indicator diagram. The particular value of $n$ may indicate whether heat is absorbed or rejected. The heat transferred is evaluated in general by means of the general energy equation of a nonflow closed system,

$$_1Q_2 = E_2 - E_1 + W_2,$$

except for the intake and exhaust processes, where $_1Q_2$ is the heat input, $(E_2 - E_1)$ the change in internal energy, and $_1W_2$ the work done by the medium. Energies E are evaluated from temperatures calculated from the characteristic gas equation using indicator diagram and engine data.

Aside from the heat exchange during each process, the energy balance for the cycle at each particular speed and load was made.

It was found that the numerical value of $n$ varied along the

compression process, being always greater than unity and increasing as TDC is approached, exceeding the value of $k = c_p/c_v$, -the exponent characteristic of a reversible adiabatic process-, at some intermediate point thus indicating a reversal of heat flow. The $n$ values are greater for higher loads and lower speeds. The $n$ value for the expansion process is very small near TDC, but increases rapidly to a value greater than the corresponding $k$ value, and remains fairly steady thereafter. The mean value of $n$ for a whole process seems to be a function of percent of full load only.

The brake thermal efficiency of the engine was found to be a function of load irrespective of speed in the range investigated. It may be expressed by a formula

$$\eta = aW^{bW+c}$$

where $\eta$ is the brake thermal efficiency, $W$ the percent of full load, and $a$,$b$, and $c$ experimentally determined constants.

The percent of fuel energy dissipated to the cooling water is fairly constant at a fixed load. The rate of heat dissipation can be expressed as

$$Q_c = K\ (F/A)\ (N)^a$$

where $Q_c$ is the rate of heat dissipation to the cooling water, $K$ a constant in units of heat, F/A the fuel-air ratio, $N$ the speed in RPM, and $a$ an experimentally determined exponent less than unity. The value of $a$ for this engine was found to be around .58.

The percent of fuel energy released to the atmosphere through the exhaust gases increases slightly with increasing speed and decreasing load. The sum of this and the other losses unaccounted for-losses due to radiation, convection, bearing friction, etc. - is fairly constant at a given load irrespective of the speed.

The heat transferred from the cylinder walls to the medium during intake is apparently a function of the cylinder wall temperature which varies with load and speed. Expressed as

percent of fuel energy it increases with increasing speed and decreasing load, and may be expressed by

$$P_i = a + bN - c(W/100)e^{\alpha}$$
$$\alpha = dW$$

where $P_i$ is the heat gained by the medium during intake in percent of fuel energy, $a$, $b$, $c$, and $d$ experimentally determined constants.

The heat transfed from the cylinder walls to the medium during the compression process decreases with decreasing speed and load. The direction of heat flow reverses after a certain point as the speed or load continue to decrease. The amount in percent of fuel energy may be expressed as

$$P_c = a + (N/100)\ (b + cWe^{\alpha})$$
$$\alpha = dW$$

where $P_c$ is the heat gained by the medium during compression in percent of fuel energy, and $a$, $b$, $c$, and $d$ experimentally determined constants.

The heat loss during the combustion period apparently takes place mainly through radiation to the sublayer film and then by conduction to the cooling water. The percentage loss due to convection becomes larger as the combustion temperature is reduced with decreasing load and speed. The loss in percent of fuel energy may be given by

$$P_b = a + bN + cWe^{-\alpha}$$
$$\alpha = dW$$

where $P_b$ is the heat lost by the medium during combustion in percent of fuel energy, and $a$, $b$, $c$, and $d$ experimentally determined constants.

The heat loss during expansion is directly proportional to the fuel-air ratio at a constant speed, and is greater at higher speeds. The heat loss per unit time may be given by

$$Q_e = a(F/A)\ (N/100)^{-b} + cN + d$$

where $Q_e$ is the rate of heat loss by the medium during expansion and $a$, $b$, $c$, and $d$ experimentally determined constants.

The mechanical type of p-v indicator appears to give satisfactory results in the investigation of the nature of the processes that take place in a moderate speed internal combustion engine.

## VITA

Cheng Shih was born on November 5, 1916, in Wukang, Hunan, China. After graduating from Chunghwa Vocational School in 1934, he worked as laboratory assistant in Natioanl Chaotung University, then entered National Peiyang University and received his degree of Bachelor of Science in Mechanical Engineering in 1939. After leaving college he worked two years in Hangyang Arsenal, then joined the Chinese Army. Upon discharge at the end of 1946, he worked in the Central Shipbuilding Corporation in Shanghai as Assistant Engineer until the Fall of 1947 when he went to the United States and entered the Graduate College of the University of Illinois, and received his degree of Master of Science in Mechanical Engineering in 1948. He held a University Fellowship in the academic year 1949-50. He is a member of Pi Tau Sigma.

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